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# AUTOMAINTENANCE WITHOUT STIMULUS-CHANGE REINFORCEMENT: TEMPORAL CONTROL OF KEY PECKS[1]

JOEL MYERSON, WILLIAM A. MYERSON, AND B. KENT PARKER

CALIFORNIA INSTITUTE OF TECHNOLOGY, BAYLOR COLLEGE OF MEDICINE, AND WEST VIRGINIA UNIVERSITY

Yoked pairs of experimentally naive pigeons were exposed to a modified autoshaping procedure in which key pecking by the leader birds postponed both keylight termination and access to grain for the leader and the follower bird. Key pecking developed and was maintained in all birds and continued through two reversals of roles in the yoked procedure. Although temporal control developed more slowly in follower birds, asymptotic temporal distributions of key pecking were similar for all birds in both leader and follower roles; maximum responding occurred soon after keylight onset and decreased to a minimum prior to reinforcement. Response distributions for both leader and follower birds were described by Killeen's (1975) mathematical model of temporal control. Follower birds received response-independent reinforcement, and the development by these birds of temporal distributions which are minimal immediately prior to reinforcement is without precedent in Pavlovian appetitive conditioning. However, maintenance of key pecking by the leader birds, whose responses postponed both stimulus-change and food reinforcement, supports an interpretation of autoshaped and automaintained key pecking as responding *elicited* by signaled grain presentation.

*Key words:* automaintenance, temporal control, stimulus-change reinforcement, autoshaping, key peck, pigeons

Brown and Jenkins (1968) demonstrated that when presentation of grain is signaled by key illumination, experimentally naive pigeons will come to peck the illuminated key. Such "autoshaped" key pecking may persist even though grain presentation is response independent (positive automaintenance, e.g., Brown & Jenkins), or indeed, even when responding prevents food reinforcement (negative automaintenance, e.g., Williams & Williams, 1969). Therefore Williams and Williams (1969) concluded that pecking can be maintained by certain stimulus-reinforcer relationships, independent of explicit or adventitious contingencies between response and reinforcer.

Recently, however, Hursh, Navarick, and Fantino (1974) reported that reinforcement by stimulus change is responsible for the negative automaintenance phenomenon. This finding poses a problem for theoretical analyses of autoshaping and automaintenance that emphasize stimulus-reinforcer pairings and the parallels with Pavlovian conditioning (e.g., Hearst & Jenkins, 1974; Moore, 1973; Schwartz & Gamzu, 1977). A further problem is that temporal distributions of autoshaped key pecking are often quite unlike those of conditioned responses with appetitive Pavlovian procedures (Deich & Wasserman, 1977; Newlin & LoLordo, 1976; Wasserman, 1973). These two issues are discussed separately below in this article.

## *Stimulus-Change Reinforcement*

In the negative automaintenance procedure of Williams and Williams (1969), responding prevented grain presentation and produced keylight termination. Hursh et al. (1974) reported that key pecking maintained by the negative automaintenance procedure could be extinguished if responding prevented grain presentation and postponed keylight termination. They concluded that keylight termination was reinforcing, either because of pairing with grain presentation (Schwartz, 1972) or because intermittent food presentation en-

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hances sensory reinforcement (Herrnstein & Loveland, 1972; Osborne & Shelby, 1975; Wallace, Osborne, Norborg, & Fantino, 1973). Even when key pecks prevent grain presentation without affecting stimulus duration (Schwartz, 1972), maintenance of responding might be due to adventitious reinforcement by stimulus change as the temporal relationship of key pecks to keylight termination is unspecified.

In the present study, we tested whether or not autoshaped key pecking could be maintained without reinforcement by either food or stimulus change. Key illumination signaled grain presentation, but key pecking postponed *both* access to grain and keylight termination in order to minimize the reinforcement of key pecking by either food or stimulus change. Generation and maintenance of key pecking with this procedure would strongly suggest that automaintenance is due to elicitation of key pecking.

### *Temporal Control*

In appetitive Pavlovian conditioning as in periodic operant reinforcement schedules, the probability of response is greatest just before food presentation (Ferster & Skinner, 1957; Pavlov, 1960). In automaintenance, on the other hand, the probability of response often decreases prior to food presentation (Deich & Wasserman, 1977; Newlin & LoLordo, 1976; Wasserman, 1973). Such distributions appear inconsistent with an account of the automaintenance of key pecking in terms of either Pavlovian stimulus-reinforcer associations or instrumental response-reinforcer associations.

Killeen (1975) has recently proposed a mathematical model for the temporal control of behavior that represents an alternative to traditional formulations. According to Killeen, this model may be generalized to all behaviors maintained by schedules of food presentation. Although Killeen discussed temporal control of operant, respondent, adjunctive (Falk, 1971), and interim (Staddon & Simmelhaag, 1971) behaviors, the model has not been tested with regard to autoshaped and automaintained key pecking. In the present experiment, temporal distributions of responding were examined, and the applicability of Killeen's model of temporal control was assessed. Yoked controls were employed to differentiate any effects of response-contingent delay of reinforcement from those of variable trial duration.

## METHOD

### *Subjects*

Six experimentally naive Silver King pigeons served at 80% of their free-feeding weights.

### *Apparatus*

Two identical two-key operant chambers measuring 34 by 28 by 28 cm were used. In each chamber, the right key aperture was covered by aluminum; the left response key, 2.5 cm in diameter, was located 22.5 cm above the chamber floor and 6.0 cm to the left of the grain feeder, center to center. The key could be transilluminated with a white light by a miniature display projector (Industrial Electronics Engineers Series 10) and required a minimum force of .5 N to operate. The feeder aperture measured 5.0 by 5.0 cm, and the bottom of the aperture was 8.0 cm above the chamber floor. The interior walls were of burnished aluminum, and the chamber was illuminated by a 15-W AC bulb located in a recessed housing in the center of the ceiling behind a translucent white shield. White masking noise and exhaust fans operated continuously during experimental sessions. The two chambers were located in separate rooms, but were connected electronically so that stimuli presented in one chamber were presented simultaneously in the other chamber. Standard electromechanical equipment, housed in a third room, was used to control the experiment and record the data.

### *Procedure*

In one session, the subjects were trained to approach and eat from the illuminated food hopper during 3.5-sec presentations of grain. The following day, experimental training began; each subject received 30 trials consisting of key illumination followed by 3.5-sec access to grain. Duration of intertrial periods was determined by a variable-time 120-sec constant probability schedule (Fleshler & Hoffman, 1962). The houselight was on continuously during the sessions.

Subjects were paired in a "yoked-control" procedure in which only responses by the "leader" had any effect on stimulus presentations. Throughout the experiment, stimulus presentations were identical for both leader and follower members of each yoked pair. The pairs consisted of Birds 1 and 2, Birds 3 and 4, and Birds 5 and 6. Birds 1, 2, 3, and 4 were tested first. Subsequently the first condition of the experiment (Phase I) was replicated with Birds 5 and 6 in order to examine the temporal control of key pecking in more detail.

During Phase I, odd-numbered birds served as leaders. A resetting 7-sec timer governed trial durations. On trials in which there were no responses by the leader, the keylight was illuminated for 7 sec and then followed by grain presentation. On trials in which the leader pecked the response key, each peck reset the 7-sec timer, postponing both the termination of key illumination and the presentation of grain. After 40 sessions, the roles of Birds 1 and 2 and also of Birds 3 and 4 were reversed for Phase II, and Birds 2 and 4 served as leaders for 40 sessions. In Phase III, these subjects were returned to their initial roles for 20 sessions.

Birds 5 and 6 were exposed to Phase I for 56 days. During the last 14 days, an additional contingency was added to suppress intertrial key pecking by the leader, Bird 5; after all but the last 25 sec of each intertrial period had elapsed, any subsequent key pecks postponed the next trial for 25 sec.

## RESULTS

Each of the six birds made its initial key peck in either the first or second experimental session, and responding increased over the next few sessions. Although there was considerable variability in the asymptotic level of responding, both leaders and followers, i.e., yoked controls, were still key pecking at the end of Phase I (Figure 1), and the rate of responding in the presence of the keylight was at least 2.5 times the rate in its absence for all birds (Table 1). Figure 1 shows that maximum responding by two leaders and two followers, Birds 1, 2, 3, and 4, occurred early in Phase I; this was followed by a slow decrease over sesssions in the percentage of trials with at least one response. Birds 5 and 6 showed no such decline. All subjects exposed to two successive reversals of roles in the yoked control procedure continued to respond throughout Phases II and III (Figure 1).

In contrast to the intersubject variability in level of responding, there was remarkable consistency in the temporal distributions of responses both between subjects and for the same subjects in different roles. For Birds 1, 2, 3, and 4, most key pecks occurred shortly after keylight onset (Figure 2). This result was replicated with Birds 5 and 6, whose responses were recorded in 1-sec bins in order to study temporal control in more detail. The development of temporal control for this pair is shown in Figure 3. Although development typically proceeded more slowly for the follower who received response-independent reinforcement than for the leader whose pecks postponed reinforcement, asymptotic temporal distributions were very similar.

Figure 4 shows the relative frequency of response in each bin for Birds 5 and 6 at the end of Phase I. The accompanying theoretical curve is the probability density function:

$$f(t) = \frac{1}{C - I}(e^{-(t-L)/C} - e^{-(t-L)/I}). \quad (1)$$

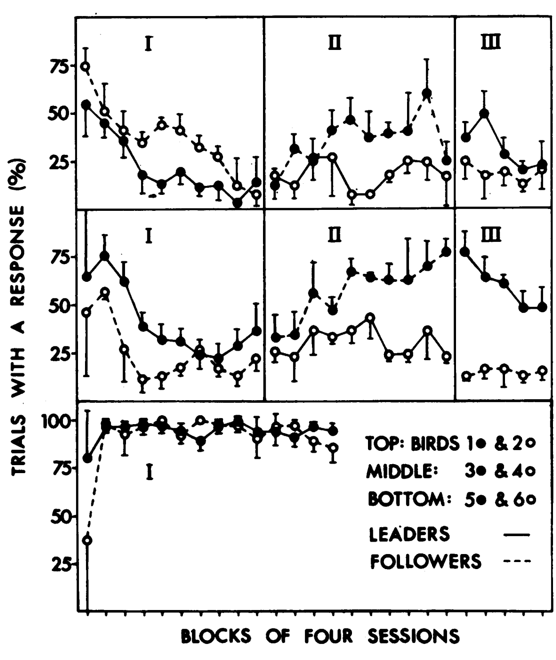


Fig. 1. Proportion of trials containing at least one key peck and standard deviations for each block of pair sessions. Responses by leader birds postponed both stimulus-change and food reinforcement for them and also for the yoked follower birds. For Birds 1, 2, 3, and 4, roles in the yoked control procedure were reversed after 40 days and again after 80 days.

Table 1

Percentage of trials with at least one key peck (R-trials), trial durations, and response rates during trial and intertrial periods for subjects in leader (L) and follower (F), i.e., yoked control, roles. Data are means for the last four sessions in each condition.

| *Subject* | *Phase* | *Role* | *R-trials* | *Trial duration* | *Rate (resp./min)* Trial | *Rate (resp./min)* Intertrial |
|---|---|---|---|---|---|---|
| 1 | I | L | 14.2 | 7.30 | 1.85 | 0.19 |
| | II | F | 25.0 | 7.23 | 2.83 | 0.00 |
| | III | L | 23.3 | 7.44 | 2.28 | 0.16 |
| 2 | I | F | 8.3 | 7.30 | 1.37 | 0.47 |
| | II | L | 16.7 | 7.23 | 1.52 | 0.50 |
| | III | F | 20.0 | 7.44 | 1.68 | 0.83 |
| 3 | I | L | 36.7 | 7.70 | 5.46 | 0.00 |
| | II | F | 78.3 | 7.47 | 30.59 | 0.10 |
| | III | L | 47.5 | 7.86 | 10.90 | 0.00 |
| 4 | I | F | 20.8 | 7.70 | 1.75 | 0.23 |
| | II | L | 22.5 | 7.47 | 1.94 | 0.01 |
| | III | F | 15.0 | 7.86 | 1.40 | 0.00 |
| 5 | I | L | 94.2 | 13.29 | 21.44 | 0.55 |
| 6 | I | F | 85.0 | 13.29 | 9.10 | 0.00 |

This is Equation 9 of Killeen (1975) with an additional minimum latency parameter, $L$. The probability density function normalizes the area under the curve at unity; the relative frequency of responses within the bin from $t_i$ to $t_f$ is given by the integral of the probability density function from $t_i$ to $t_f$ (McGill, 1963). Values of parameters are those providing the least squares best fit of the integrals of the theoretical curve to the observed relative frequency distributions with $C$ and $I$ the same for both birds and individual values of $L$. This accounted for more than 99% of the variance for each bird with $C$ equal to 1.160 sec and $I$ equal to .207 sec, and with $L$ equal to .677 and .847 for Birds 5 and 6, respectively. Employing individual values of $C$ and $I$ did not appreciably improve the fits.

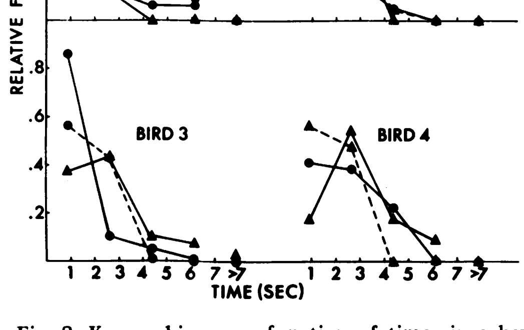


Fig. 2. Key pecking as a function of time since keylight onset. For each subject, the relative frequencies of responses collected in each of five bins are shown for the last 4 days of each phase. Dotted lines indicate each bird's reexposure to its original role in the yoked procedure.

The data were also fit using two other theoretical equations, the sum of three exponential decays (Equation 10, Killeen, 1975) and the gamma function (McGill, 1963). The three-exponential function was used by Killeen to describe adjunctive behaviors and is based on a three-step stochastic latency mechanism rather than the two-step mechanism of Equation 1 (McGill, 1963). Killeen (1979) has recently proposed the gamma function, which is based upon a Poisson process, as a possible alternative to Equation 1. However, neither the gamma function nor Killeen's (1975) Equation 10 describes the present data as well as Equation 1 (Table 2).

For Birds 1, 2, 3, and 4, the number of bins was small and the number of responses in some bins extremely low. Therefore, the relative frequency distributions for all four birds in both roles were averaged, and the resultant mean distribution was fit with Equation 1 with $L$ as the one free parameter and $C$ and $I$ as empirical constants whose values were determined from Birds 5 and 6. With $L$

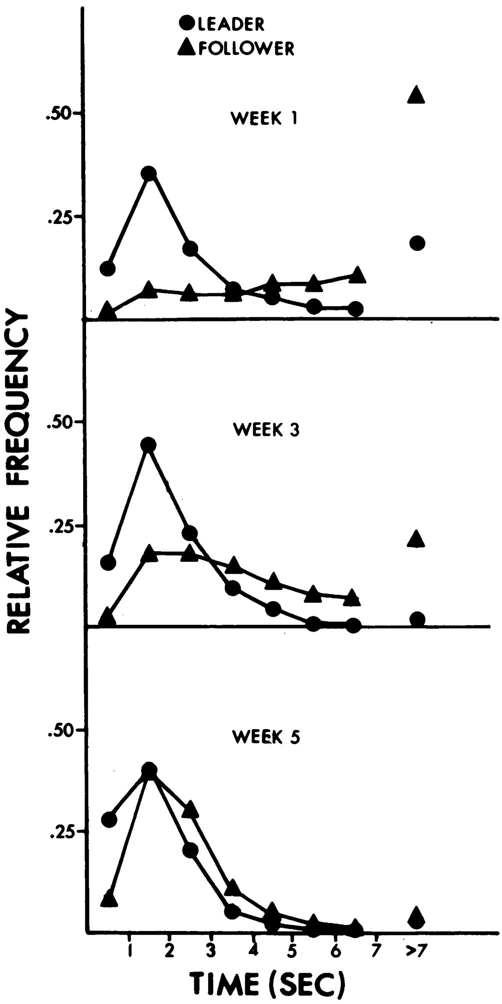


Fig. 3. Development of temporal control. The relative frequency of key pecks is shown as a function of time since keylight onset. Data are for the first, third, and fifth weeks of Phase I for Birds 5 (leader) and 6 (follower). Relative-frequency distributions obtained during the eighth week are shown in Figure 4.

equal to .483 sec, more than 99% of the variance was accounted for.

## DISCUSSION

The nature of autoshaped and automaintained key pecking was examined from two perspectives. First, we tested whether key pecking can be elicited, i.e., generated and maintained under stimulus control in the absence of response-reinforcer pairings. In order to do this, it was necessary to minimize stimulus-change reinforcement as well as food reinforcement of key pecking (Hursh et al., 1974). This was done by having key pecks postpone both keylight termination and access to grain in a modified autoshaping procedure. Second, we sought to determine if the temporal distributions of key pecking obtained with this procedure were consistent with the findings and theory of Pavlovian conditioning on the one hand, and/or with Killeen's (1975) mathematical model for temporal control on the other hand.

### *Stimulus-Change Reinforcement*

The present findings demonstrate that autoshaped key pecking may be maintained without reinforcement by either food or stimulus change. The experimentally naive leader birds of three yoked pairs acquired the key-peck response in the first experimental session, and despite the fact that their key pecking postponed both grain presentation and keylight termination, all three were still responding after 40 days. Similar results have been reported by Christoph and Hearst (Note 1). Although responding by two out of three leader birds decreased over sessions in the first phase of the present study, this does not seem to have been due to response-contingent delay of reinforcement. Two of the yoked control birds receiving response-independent reinforcement showed a comparable decline, and similar decreases occur with positive automaintenance (Moore, 1973; Newlin & LoLordo, 1976; Wasserman, 1973).

In the second phase of the experiment, roles in the yoked control procedure were reversed for two pairs. Key pecking that postponed both food and stimulus-change reinforcement was maintained in birds who had acquired the key-peck response as yoked controls receiving response-independent reinforcement. Key pecking also persisted when subjects were returned to their original roles in the third experimental phase. These results strongly support the contention of Williams and Williams (1969) that the generation and maintenance of autoshaped key pecking does not require positive response-reinforcer contingencies, either explicit or adventitious, but instead is due to the *elicitation* of key pecking by the signal for grain presentation.

Hursh et al. (1974) were unable to maintain key pecking when the opportunity for stimulus-change reinforcement was eliminated from the negative automaintenance procedure.

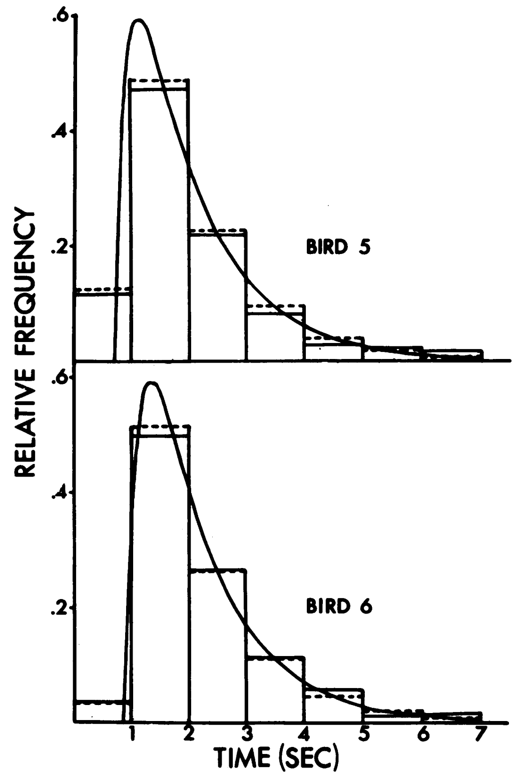


Fig. 4. Temporal control of key pecking. Solid lines indicate the relative frequency of key pecks as a function of time since keylight onset. Data are for the last 4 days of Phase I for Birds 5 (leader) and 6 (follower). The theoretical curve is the probability density function, Killeen's (1975) Equation 9 with an additional minimum latency parameter, which best described the data. Dotted lines indicate the expected relative frequency distribution, i.e., the theoretical curve integrated from the beginning to the end of each bin.

The present procedure, which did maintain nonreinforced key pecking, differed from the TOD (time-out-delay) procedure of Hursh et al. in two ways: (a) While responding postponed food reinforcement under both procedures, the delay was only 7 sec with the present procedure; with the TOD procedure, responding delayed reinforcement until the end of the subsequent trial; and (b) every key illumination was paired with grain presentation under the present procedure; with the TOD procedure, responding resulted in a decreased percentage of key illuminations being followed by grain. Intermittent light-food pairings are less effective in maintaining autoshaped key pecking (Gonzalez, 1974). Thus the present procedure differed from TOD in both stimulus-reinforcer and response-reinforcer relationships. The differences in the present procedure favor response maintenance while minimizing the effect of stimulus change as a reinforcer of key pecking.

The present results demonstrate that stimulus-change reinforcement of key pecking is not a necessary condition for automaintenance. They do not, however, rule out a role for stimulus-change reinforcement where it is permitted to operate (see Osborne, 1977, for a review). Reinforcement has been shown to affect both the pattern (Deich & Wasserman, 1977; Wasserman, 1977) and probability of autoshaped and automaintained key pecking (see Schwartz & Gamzu, 1977, for a review). Therefore, studies of elicited key pecking would seem to require attempts either to preclude

Table 2

Parameter values resulting in least squares best fits to temporal distributions (Figure 4) by definite integrals of theoretical equations.

| *Theoretical equation* | *Subject* | *Parameter values* | *Variance accounted for* |
|---|---|---|---|
| Equation 9, | 5 | $I = 1.078,\ C = 1.085$ | >74% |
| Killeen, 1975 | 6 | $I = 1.189,\ C = 1.198$ | >62% |
| (Equation 1 in text with $L = 0$). | | | |
| Equation 10, | | | |
| Killeen, 1975. | 5 | $B = .631,\ I = .668,\ C = .671$ | >90% |
| | 6 | $B = .667,\ I = .715,\ C = .719$ | >82% |
| Gamma function | 5 | $n = 5,\ \lambda = 2.725$ | >96% |
| (Equation 9, McGill, 1963). | 6 | $n = 6,\ \lambda = 3.076$ | >95% |
| Equation 1 in text. | 5 | $L = .712,\ I = .134,\ C = 1.245$ | >99% |
| | 6 | $L = .832,\ I = .245,\ C = 1.166$ | >99% |

stimulus-change reinforcement or assess the magnitude of its effect.

*Temporal Control*

The maximum probability of response occurred soon after keylight onset followed by a decrease in response probability with time. This might be attributed to response-contingent delay of reinforcement were it not that the temporal distributions for yoked controls, who received response-independent reinforcement, were of the same form as the leaders' distributions. Moreover, similar temporal distributions occur with positive automaintenance (Deich & Wasserman, 1977; Newlin & LoLordo, 1976; Wasserman, 1973) although considerable intersubject variability has been reported. In the present study, asymptotic temporal distributions took many sessions to develop with response-independent reinforcement. This suggests that the variability observed in previous studies might be due to variability in the time required to develop asymptotic temporal control.

Staddon (1972, 1977) and Staddon and Ayres (1975) have suggested that temporal behavior patterns are regulated by "internal clocks" which determine transitions between behavioral states. Killeen (1975) has proposed a mathematical model of temporal control which attempts to account for these state transitions. In its basic form, response distributions similar to those observed in the present study are described by the algebraic sum of two exponential decay functions (see Equation 1 above). The time constant, $I$, of one of the exponential decays determines the ascending portion of the curve. Killeen (1975) and Osborne, Rysberg, and Killeen (1977) have suggested that it is a measure of inhibition by events signaling a period during which reinforcement is unlikely. The other time constant, $C$, determines the descending portion of the curve and may reflect competition by more terminal behaviors (Killeen, 1975; Osborne et al., 1977; Staddon, 1977; Staddon & Simmelhaag, 1971). We have employed an additional parameter, $L$, which represents the minimum latency. This parameter may be related to the time required for the birds to orient toward the key after it is illuminated. When the interval in which behavior is temporally controlled is short, as in the present instance, temporal response distributions are likely to be more affected by factors such as orientation than when longer intervals are involved.

With the addition of the minimum latency parameter, this model (Equation 1) adequately described temporal control in the present study. Using the probability density function, the relative frequency of key pecking by all subjects in either role could be described using the same two time constants for the exponential decay functions while adjusting the minimum latency parameter. Autoshaped and automaintained key pecking thus may be added to the list of behaviors whose temporal distributions are accurately described by Killeen's (1975) model of temporal control.

Temporal distributions in which the probability of response is lowest immediately before reinforcement are contrary to expectations for an operant response. Moreover, the analogy between autoshaping and Pavlovian conditioning does not account for such distributions. Wasserman (1973) has pointed out that they are the opposite of those reported for salivation (Pavlov, 1960; Sheffield, 1965; see Kimmel & Burns, 1975, for a review) and explained on the basis of "inhibition of delay" by Pavlov (1960).

Nevertheless, key pecking by leader birds in the present study may be characterized as responding *elicited* by the signal for grain presentation because the contingency precluded response-reinforcer pairings. Key pecking by yoked controls receiving response-independent reinforcement may also be characterized as elicited because of the extremely low frequency of response-reinforcer pairings as indicated by asymptotic temporal distributions. In addition, development of temporal control in birds receiving response-independent reinforcement proceeded in a manner opposite to differentiation of an operant. There was a gradual decrease over sessions in the frequency of those responses, key pecks occurring more than several seconds after keylight onset, which were most contiguous with reinforcement. It should also be noted that this is the opposite of the developmental pattern for inhibition of delay in a respondent (Pavlov, 1960; Kimmel & Burns, 1975).

Temporal distributions in which responding decreases prior to reinforcement occur in various situations where one response or response class is displaced by another. Interim

(Staddon & Simmelhaag, 1971) and adjunctive (Falk, 1971) behaviors decrease in probability as they are displaced by terminal behaviors (Staddon & Simmelhaag, 1971; see Staddon, 1977, for a review). The displacement of one operant by another can also generate such distributions (Nevin, 1974). Similarly in automaintenance, pecking elicited by and directed at the illuminated key may be displaced by a subsequent behavior, usually hopper-directed pecking, before grain presentation (Newlin & LoLordo, 1976; and informal observations in the present study). As a consequence, key pecking is concentrated in the period immediately following keylight onset.

The parameter $C$ governs the descending portion of Killeen's (1975) theoretical function and may represent the displacement of the recorded behavior by competing terminal responses. In the present study, response-contingent delay of reinforcement for leaders might have been expected to produce faster decay of key pecking for leaders than for followers receiving response-independent reinforcement. However, the similarity of values of $C$ for leaders and followers suggests that the reinforcing effect of grain presentation was of less salience than its eliciting effect on terminal responses such as hopper-directed pecking.

The present results demonstrate that key pecking may be elicited by the signal for grain presentation and maintained without reinforcement by either food or stimulus change. However, a Pavlovian analysis of autoshaping and automaintenance is not supported by either the pattern of development of temporal control or the asymptotic form of temporal response distributions. Rather, elicited key pecking resembles in this respect a diverse collection of skeletal responses from different behavioral categories. Similarities which cut across categories in this way suggest that the properties in common may be more fundamental than the differences (Killeen, 1975). In particular, competitive interaction between response classes seems to be the basis for similarities in temporal control of elicited key pecking and a variety of other behaviors (Staddon, 1977). Such interactions deserve further scientific attention because of both their fundamental nature and their amenability to precise mathematical description at the level of the individual organism as exemplified in the present study.

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